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AUG 79 P N SOMERVILLE, S J BEAN F19628-77-C-0080

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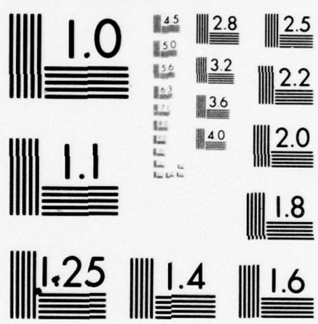

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LEVEL II

SOME ADDITIONAL MODELS FOR RAINFALL

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Scientific Report No. 6

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The Kappa distribution, which has a closed form cumulative distribution, is used to model daily rainfall for 24 stations distributed throughout the world. Separate models are given for each month. Estimates of the amounts of error in using the model to predict daily rainfall less than a stated amount are given.

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TABLE OF CONTENTS

1. INTRODUCTION

Daily rainfall records are available for many stations. To determine the climatic probability of rain at some future date for a specific station, it is possible to retrieve these records and to obtain an empirical estimate. This can be a slow, cumbersome and costly process. In Scientific Report No. 2 two different models were developed so as to effectively compact the historical data and make possible rapid recall and reuse. The models were adapted for ten weather stations.

In this report we use one of the above models (Kappa) for an additional fourteen stations. For completeness the results for the original ten stations are also included. The data used to develop the models was extracted from the "Revised Uniform Summary of Weather Observations" (RUSSWO's) prepared by the Data Processing Division of the Air Weather Service, or the "Summary of Meteorological Observations, Surface" (SMOS) prepared by the Naval Weather Service Detachments.

2. MODELING DAILY RAINFALL

An elementary, but useful, method of developing a model for data is the following. First make a histogram of the data, and then "smooth" the histogram to get a frequency distribution (probability density function). The probability of a value of the variable less than some fixed amount is then estimated by the proportion of the area under the frequency distribution to the left of that amount.

There are usually a number of curves or distributions which can be used to fit the data. In this report, we use the three-parameter Kappa* distribution. The cumulative distribution function of the Kappa distribution is in closed form. That is, probabilities can be obtained by direct substitution and no numerical integration or other approximations are required. The cumulative distribution function is given by

$$F(x) = \left[(x/\beta)^{\alpha\theta} \Big/ (\alpha+(x/\beta)^{\alpha\theta}) \right]^{1/\alpha} \quad \alpha,\beta,\theta>0.$$

3. ESTIMATION OF THE PARAMETER VALUES

A standard (and efficient) method of estimation of the parameters of a probability density function is by the method of maximum likelihood. The estimates for the Kappa distribution require the simultaneous solution of three non-linear equations, which can be accomplished by iteration.

Instead of using the method of maximum likelihood to estimate the three parameters of the Kappa distribution, the following method was used.** The values of the empirical cumulative distribution function were regressed on the Kappa cumulative distribution function. The estimates of α, β and θ are those which minimize the sum of the squares of the differences between the model or theoretical cumulative distribution (Kappa) and the empirical cumulative distribution. This is the same as choosing those estimates of α,β and θ which minimize the sum of the squares of the differences between the empirical probabilities and the model theoretical probabilities.

The RUSSWO's give the frequency for the following daily precipitation values (inches): none, trace, .01, .02-.05, .06-.10, .11-.25, .26-.50, .51-1.00, 1.01-2.50, 2.51-5.00, 5.01-10.00, 10.01-20. The frequencies for "none" and "trace" were combined, and the empirical and model frequencies were compared for the values .005, .015, .055, .105, .255, .505, 1.005, 2.505, 5.005, 10.005 and 20.005. It should be noted that "no precipitation" is thus equated to "less than .005 inches."

* The Kappa distribution was introduced by P. W. Mielke, Jr. (1973) in "Another family of distributions for describing and analysing precipitation data", J. Appl. Meteorol., 12: 275-280

** A more detailed explanation of the method is planned for Scientific Report Number 8 "Use of Non-linear Regression to Estimate a Cumulative Distribution Function."

Since the object is not to estimate α, β and θ for their own sake, but only as a means of obtaining probabilities, the method used has considerable intuitive appeal. The authors intend to exhibit and discuss a number of these desirable properties in a separate publication at a later date.

Estimation of α, β and θ using existing non-linear regression programs proved difficult and time consuming. Instead, a simple three dimensional grid search procedure was used. The sum of squares of the difference between the model and the empirical probabilities was calculated for each point on the grid, with the estimates being those for which the sum of the squares was smallest.

Tables of the coefficients of the models for the stations are given in Section 6.

Table 3.1 gives the observed and model values for Mildenhall, England for July.

x	.005	.015	.055	.105	.255	.505	1.005	2.505	5.005	10.005
Observed	.577	.635	.749	.813	.922	.964	.996	1.000	1.000	1.000
Model	.582	.657	.758	.814	.897	.967	1.000	1.000	1.000	1.000

TABLE 3.1

Observed and Fitted Values for Prob (X < x)
X is Rainfull (inches) for Mildenhall, England, July

4. GOODNESS OF FIT OF THE MODELS

The measure of goodness of fit used was the root mean square of the difference between the empirical and the model cumulative distribution functions (empirical and model probabilities) at the rainfall amounts .005, .015, ..., 20.005. Since in many cases, no frequencies are recorded for the upper categories, the root mean square values tabulated are optimistic in practice, and should be multiplied by the factor (no. of categories/no. of categories with zero frequency). This factor is as large or larger than 2 in some cases.

The RMS of the model fits are given for each station for each month in the tables in Section 6.

5. USE OF THE MODELS

a) Suppose we wish to estimate the probability of more than .1, .3 and .5 inches of rain on July 10, 1983 in Mildenhall England? From the tables

in Section 6, we have $\alpha = 100.0$, $\beta = .450$, $\theta = .110$. Putting $x = .1, .3, .5$ and 1.0 in the formula,

$$F(x) = \left[(x/\beta)^{\alpha\theta} \Big/ (\alpha + (x/\beta)^{\alpha\theta}) \right]^{1/\alpha}$$

we obtain $F(x) = .809, .913, .966$.

The probabilities of more than .1, .3 and .5 inches of rain are thus estimated as .191, .087 and .034 respectively.

b) What is the probability of no rain at Mildenhall on July 10, 1983?

We interpret "no rain" to mean less than .005 inches and substitute $x = .005$ in the formula for $F(x)$. We obtain .582 as the probability of no rain.

6. TABLES OF COEFFICIENTS FOR THE MODELS

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - ASCENSION ISLAND

	ALPHA	BETA	THETA	RMS
Jan	110.0	0.100	0.050	0.017
Feb	120.0	0.100	0.050	0.012
Mar	100.0	0.100	0.080	0.010
Apr	50.0	0.100	0.080	0.008
May	80.0	0.100	0.050	0.007
Jun	70.0	0.100	0.080	0.006
Jul	120.0	0.100	0.080	0.010
Aug	100.0	0.100	0.080	0.009
Sep	120.0	0.100	0.110	0.010
Oct	120.0	0.100	0.140	0.017
Nov	120.0	0.100	0.080	0.019
Dec	120.0	0.100	0.080	0.012

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - BALBOA

	ALPHA	BETA	THETA	RMS
Jan	40.0	0.100	0.050	0.010
Feb	100.0	0.100	0.020	0.003
Mar	120.0	0.100	0.020	0.011
Apr	30.0	0.100	0.050	0.013
May	20.0	0.625	0.170	0.015
Jun	40.0	0.975	0.170	0.019
Jul	40.0	0.800	0.200	0.015
Aug	30.0	0.800	0.200	0.008
Sep	40.0	0.800	0.170	0.009
Oct	20.0	0.800	0.230	0.014
Nov	50.0	1.325	0.230	0.022
Dec	90.0	1.150	0.110	0.010

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - BANGOR

	ALPHA	BETA	THETA	RMS
Jan	40.0	0.450	0.110	0.024
Feb	40.0	0.450	0.110	0.022
Mar	110.0	0.975	0.080	0.017
Apr	50.0	0.450	0.110	0.015
May	90.0	0.800	0.080	0.016
Jun	100.0	0.800	0.080	0.013
Jul	50.0	0.450	0.080	0.007
Aug	40.0	0.275	0.080	0.009
Sep	90.0	0.625	0.080	0.014
Oct	40.0	0.450	0.080	0.010
Nov	90.0	1.675	0.080	0.025
Dec	110.0	0.975	0.080	0.014

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - BEDFORD

	ALPHA	BETA	THETA	RMS
Jan	120.0	1.150	0.080	0.017
Feb	90.0	0.975	0.080	0.014
Mar	100.0	0.975	0.080	0.014
Apr	120.0	1.325	0.080	0.021
May	90.0	0.975	0.080	0.015
Jun	70.0	0.450	0.080	0.013
Jul	120.0	1.325	0.050	0.015
Aug	30.0	0.275	0.080	0.018
Sep	110.0	0.975	0.050	0.011
Oct	120.0	1.325	0.050	0.013
Nov	90.0	0.975	0.080	0.017
Dec	90.0	0.800	0.080	0.013

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - BERMUDA

	ALPHA	BETA	THETA	RMS
Jan	20.0	0.275	0.170	0.015
Feb	40.0	0.450	0.170	0.014
Mar	30.0	0.450	0.140	0.012
Apr	80.0	0.625	0.080	0.006
May	30.0	0.275	0.080	0.015
Jun	120.0	1.500	0.080	0.017
Jul	40.0	0.450	0.110	0.017
Aug	80.0	0.800	0.110	0.009
Sep	80.0	1.150	0.110	0.017
Oct	20.0	0.450	0.140	0.011
Nov	80.0	0.800	0.110	0.013
Dec	40.0	0.450	0.140	0.011

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - CHRISTCHURCH

	ALPHA	BETA	THETA	RMS
Jan	60.0	0.275	0.080	0.007
Feb	80.0	0.275	0.080	0.009
Mar	100.0	0.450	0.080	0.009
Apr	80.0	0.450	0.080	0.010
May	60.0	0.450	0.080	0.013
Jun	70.0	0.275	0.080	0.010
Jul	40.0	0.275	0.110	0.012
Aug	60.0	0.275	0.080	0.008
Sep	60.0	0.275	0.080	0.011
Oct	40.0	0.100	0.080	0.012
Nov	70.0	0.450	0.080	0.008
Dec	120.0	0.625	0.050	0.013

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - FURUMAKI

	ALPHA	BETA	THETA	RMS
Jan	20.0	0.275	0.200	0.014
Feb	20.0	0.275	0.200	0.013
Mar	40.0	0.275	0.110	0.013
Apr	110.0	0.800	0.080	0.010
May	60.0	0.450	0.080	0.007
Jun	120.0	1.500	0.080	0.019
Jul	20.0	0.275	0.110	0.013
Aug	110.0	0.975	0.080	0.008
Sep	80.0	1.150	0.110	0.013
Oct	110.0	0.800	0.080	0.009
Nov	90.0	0.625	0.110	0.014
Dec	40.0	0.275	0.170	0.015

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - GOOSE

	ALPHA	BETA	THETA	RMS
Jan	120.0	0.625	0.140	0.011
Feb	30.0	0.275	0.140	0.008
Mar	60.0	0.450	0.110	0.010
Apr	60.0	0.450	0.140	0.016
May	120.0	0.625	0.110	0.015
Jun	30.0	0.275	0.140	0.013
Jul	20.0	0.275	0.140	0.014
Aug	20.0	0.275	0.140	0.013
Sep	30.0	0.275	0.140	0.013
Oct	90.0	0.450	0.110	0.010
Nov	30.0	0.275	0.140	0.010
Dec	40.0	0.275	0.170	0.008

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - HILL AFB

	ALPHA	BETA	THETA	RMS
Jan	70.0	0.450	0.080	0.012
Feb	60.0	0.275	0.080	0.012
Mar	120.0	0.450	0.080	0.014
Apr	40.0	0.275	0.080	0.022
May	120.0	0.625	0.050	0.011
Jun	70.0	0.275	0.050	0.013
Jul	120.0	0.100	0.020	0.005
Aug	110.0	0.275	0.020	0.014
Sep	120.0	0.450	0.020	0.013
Oct	80.0	0.275	0.050	0.012
Nov	70.0	0.275	0.080	0.018
Dec	110.0	0.625	0.080	0.017

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - HONOLULU

	ALPHA	BETA	THETA	RMS
Jan	20.0	0.100	0.080	0.012
Feb	20.0	0.100	0.080	0.005
Mar	110.0	0.625	0.050	0.014
Apr	40.0	0.100	0.080	0.010
May	70.0	0.100	0.050	0.007
Jun	120.0	0.100	0.050	0.012
Jul	80.0	0.100	0.050	0.011
Aug	70.0	0.100	0.050	0.011
Sep	70.0	0.100	0.050	0.010
Oct	30.0	0.100	0.080	0.011
Nov	30.0	0.100	0.080	0.014
Dec	20.0	0.100	0.080	0.005

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - LAJES FIELD

	ALPHA	BETA	THETA	RMS
Jan	20.0	0.450	0.230	0.011
Feb	20.0	0.450	0.200	0.011
Mar	60.0	0.800	0.170	0.012
Apr	50.0	0.450	0.110	0.013
May	70.0	0.275	0.110	0.014
Jun	80.0	0.275	0.080	0.011
Jul	30.0	0.100	0.080	0.008
Aug	20.0	0.100	0.110	0.012
Sep	30.0	0.275	0.110	0.007
Oct	40.0	0.450	0.170	0.016
Nov	30.0	0.450	0.170	0.015
Dec	40.0	0.450	0.170	0.012

PARAMETERS OF KAPPA DISTRIBUTION
RMS OF FIT
PRECIPITATION - MANILA

	ALPHA	BETA	THETA	RMS
Jan	120.0	0.100	0.050	0.013
Feb	120.0	0.100	0.020	0.010
Mar	120.0	0.100	0.020	0.008
Apr	120.0	0.100	0.020	0.003
May	110.0	1.150	0.050	0.009
Jun	20.0	0.625	0.140	0.012
Jul	40.0	0.975	0.200	0.015
Aug	20.0	1.325	0.230	0.021
Sep	60.0	1.325	0.230	0.014
Oct	40.0	0.800	0.140	0.010
Nov	100.0	0.975	0.080	0.015
Dec	110.0	0.625	0.050	0.013

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - MCMURDO SOUND

	ALPHA	BETA	THETA	RMS
Jan	90.0	0.100	0.020	0.006
Feb	50.0	0.100	0.050	0.007
Mar	120.0	0.100	0.050	0.012
Apr	120.0	0.100	0.080	0.009
May	70.0	0.100	0.050	0.009
Jun	80.0	0.100	0.080	0.013
Jul	90.0	0.100	0.050	0.011
Aug	90.0	0.100	0.080	0.009
Sep	70.0	0.100	0.050	0.011
Oct	120.0	0.100	0.050	0.014
Nov	100.0	0.100	0.020	0.011
Dec	120.0	0.275	0.020	0.013

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - MIDWAY

	ALPHA	BETA	THETA	RMS
Jan	30.00	0.450	0.140	0.015
Feb	30.00	0.450	0.110	0.015
Mar	40.00	0.275	0.110	0.013
Apr	20.00	0.100	0.080	0.009
May	40.00	0.100	0.080	0.012
Jun	40.00	0.275	0.080	0.013
Jul	30.00	0.275	0.140	0.013
Aug	50.00	0.450	0.110	0.014
Sep	30.00	0.275	0.140	0.013
Oct	40.00	0.275	0.140	0.019
Nov	50.00	0.450	0.110	0.019
Dec	40.00	0.450	0.140	0.012

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - MILDENHALL

	ALPHA	BETA	THETA	RMS
Jan	120.0	0.275	0.170	0.015
Feb	120.0	0.275	0.140	0.010
Mar	20.0	0.100	0.140	0.007
Apr	120.0	0.275	0.140	0.011
May	60.0	0.275	0.110	0.010
Jun	70.0	0.450	0.080	0.011
Jul	100.0	0.450	0.110	0.011
Aug	50.0	0.275	0.140	0.011
Sep	50.0	0.275	0.110	0.008
Oct	20.0	0.100	0.110	0.009
Nov	60.0	0.275	0.170	0.007
Dec	60.0	0.275	0.140	0.011

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - NENANA

	ALPHA	BETA	THETA	RMS
Jan	50.0	0.100	0.080	0.009
Feb	50.0	0.100	0.080	0.009
Mar	120.0	0.100	0.080	0.011
Apr	120.0	0.100	0.050	0.010
May	60.0	0.100	0.050	0.004
Jun	100.0	0.450	0.080	0.012
Jul	90.0	0.450	0.110	0.015
Aug	70.0	0.450	0.110	0.012
Sep	30.0	0.100	0.110	0.015
Oct	70.0	0.100	0.110	0.009
Nov	110.0	0.100	0.110	0.010
Dec	110.0	0.100	0.110	0.009

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - OKINAWA

	ALPHA	BETA	THETA	RMS
Jan	20.0	0.275	0.170	0.014
Feb	30.0	0.450	0.140	0.008
Mar	90.0	0.975	0.110	0.011
Apr	40.0	0.625	0.110	0.015
May	40.0	0.800	0.140	0.011
Jun	40.0	1.675	0.110	0.021
Jul	60.0	0.975	0.080	0.009
Aug	90.0	1.150	0.140	0.018
Sep	40.0	0.625	0.110	0.010
Oct	20.0	0.275	0.110	0.009
Nov	60.0	0.975	0.080	0.012
Dec	70.0	0.625	0.110	0.008

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - PATRICK AFB

	ALPHA	BETA	THETA	RMS
Jan	40.0	0.100	0.050	0.015
Feb	110.0	0.975	0.050	0.011
Mar	100.0	0.800	0.050	0.009
Apr	30.0	0.100	0.050	0.017
May	110.0	0.975	0.050	0.010
Jun	100.0	1.325	0.080	0.013
Jul	80.0	0.800	0.080	0.016
Aug	110.0	1.150	0.080	0.008
Sep	40.0	0.975	0.110	0.010
Oct	60.0	0.800	0.080	0.008
Nov	70.0	0.275	0.050	0.006
Dec	80.0	0.275	0.050	0.007

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - SAIGON

	ALPHA	BETA	THETA	RMS
Jan	120.0	0.100	0.020	0.007
Feb	120.0	0.100	0.020	0.033
Mar	120.0	0.100	0.020	0.013
Apr	80.0	0.100	0.050	0.011
May	90.0	1.325	0.170	0.025
Jun	30.0	1.150	0.230	0.027
Jul	50.0	1.500	0.230	0.025
Aug	50.0	1.675	0.230	0.035
Sep	40.0	1.675	0.230	0.035
Oct	20.0	0.800	0.230	0.020
Nov	120.0	0.975	0.080	0.010
Dec	50.0	0.100	0.050	0.016

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - SCOTT AFB

	ALPHA	BETA	THETA	RMS
Jan	110.0	0.625	0.050	0.010
Feb	100.0	0.975	0.050	0.018
Mar	80.0	0.625	0.080	0.011
Apr	100.0	1.150	0.080	0.021
May	120.0	0.975	0.080	0.016
Jun	40.0	0.450	0.080	0.018
Jul	120.0	1.325	0.050	0.015
Aug	90.0	0.625	0.050	0.013
Sep	120.0	0.975	0.050	0.010
Oct	90.0	0.625	0.050	0.009
Nov	120.0	1.150	0.050	0.013
Dec	110.0	0.975	0.050	0.014

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - SHEMYA

	ALPHA	BETA	THETA	RMS
Jan	60.0	0.275	0.230	0.034
Feb	120.0	0.275	0.230	0.028
Mar	110.0	0.275	0.200	0.017
Apr	20.0	0.100	0.200	0.017
May	50.0	0.275	0.140	0.015
Jun	20.0	0.100	0.140	0.008
Jul	40.0	0.275	0.140	0.011
Aug	30.0	0.275	0.140	0.014
Sep	40.0	0.275	0.170	0.016
Oct	20.0	0.275	0.230	0.030
Nov	80.0	0.450	0.230	0.041
Dec	50.0	0.275	0.230	0.013

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - THULE AB

	ALPHA	BETA	THETA	RMS
Jan	120.0	0.100	0.050	0.010
Feb	110.0	0.100	0.050	0.009
Mar	120.0	0.100	0.050	0.017
Apr	120.0	0.100	0.050	0.017
May	120.0	0.100	0.080	0.009
Jun	120.0	0.100	0.020	0.011
Jul	60.0	0.100	0.050	0.007
Aug	110.0	0.100	0.080	0.010
Sep	70.0	0.100	0.080	0.004
Oct	110.0	0.100	0.110	0.007
Nov	120.0	0.100	0.080	0.006
Dec	120.0	0.100	0.080	0.010

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - TORREJON

	ALPHA	BETA	THETA	RMS
Jan	100.0	0.450	0.080	0.016
Feb	90.0	0.625	0.080	0.017
Mar	100.0	0.275	0.080	0.014
Apr	80.0	0.275	0.080	0.016
May	100.0	0.450	0.050	0.013
Jun	50.0	0.100	0.050	0.008
Jul	120.0	0.100	0.020	0.011
Aug	120.0	0.100	0.020	0.011
Sep	70.0	0.275	0.050	0.008
Oct	60.0	0.275	0.080	0.018
Nov	120.0	0.800	0.080	0.012
Dec	70.0	0.275	0.080	0.010

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - TRIPOLI

	ALPHA	BETA	THETA	RMS
Jan	60.0	0.275	0.080	0.018
Feb	120.0	0.275	0.050	0.009
Mar	120.0	0.275	0.020	0.014
Apr	110.0	0.100	0.020	0.007
May	120.0	0.100	0.020	0.023
Jun	120.0	0.100	0.020	0.036
Jul	120.0	0.100	0.020	0.040
Aug	120.0	0.100	0.020	0.038
Sep	120.0	0.100	0.020	0.020
Oct	40.0	0.100	0.050	0.009
Nov	100.0	0.625	0.050	0.010
Dec	120.0	0.800	0.080	0.015

PARAMETERS OF KAPPA DISTRIBUTION

RMS OF FIT

PRECIPITATION - WAKE ISLAND

	ALPHA	BETA	THETA	RMS
Jan	30.0	0.100	0.110	0.007
Feb	120.0	0.275	0.080	0.013
Mar	20.0	0.100	0.110	0.010
Apr	60.0	0.275	0.140	0.009
May	80.0	0.275	0.140	0.013
Jun	80.0	0.275	0.170	0.012
Jul	30.0	0.275	0.200	0.018
Aug	20.0	0.450	0.170	0.017
Sep	40.0	0.450	0.200	0.018
Oct	40.0	0.450	0.200	0.017
Nov	50.0	0.275	0.140	0.012
Dec	20.0	0.100	0.110	0.012